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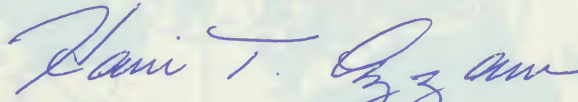
possessed by just a few

. . . . but Dow Corning friction and wear testing machines permit you to accurately predict the in-service behavior of metals and lubricants by faithful simulation of actual operating conditions.

Excessive wear and ultimate failure of aluminum bronze bushings used in critical space vehicle applications was investigated and solved by TRW, with the help of an LFW-1 testing machine, manufactured by Dow Corning. The enclosed reprint of an article by Frans G. A. DeLaat, which appeared in the August, 1968 issue of Research/Development magazine, reports on the test procedures and conclusions.

Become a prognosticator. A reply card is enclosed for your convenience in requesting additional information about testing machines from Dow Corning.

Very truly yours,



H. T. Azzam, Manager
Testing Machines Department

P. S. We thought you would be interested in the attached LFW-1 standard, which will appear in the 1969 ASTM Standards handbook. This method was prepared under the joint sponsorship of the American Society of Lubrication Engineers with the cooperation of the Coordinating Research Council (CRC).

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Attn: Mr. Hani Azzam R/D

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AMERICAN SOCIETY FOR TESTING AND MATERIALS

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Standard Method for

CALIBRATION AND OPERATION OF THE ALPHA MODEL LFW-1 FRICTION AND WEAR TESTING MACHINE¹



ASTM Designation: D 2714 - 68

This Standard has been approved by the sponsoring committees and accepted by the cooperating Societies in accordance with established procedures.

1. Scope

1.1 This method covers the calibration and operation of a ring and block friction and wear testing machine.

2. Summary of Method

2.1 The test machine is operated using a steel test ring rotating against a steel test block, the specimen assembly being partially immersed in the lubricant sample. The velocity of the test ring is 26 ± 0.52 ft/min (7.9 ± 0.16 m/min) which is equivalent to a spindle speed of 72 ± 1 rpm. (The test ring has a diameter of $1.3775 + 0.0001, -0.0005$ in.) ($35 + 0.0025, -0.1270$ mm.) The specimens are subjected to 150-lb (68-kg) normal load applied by 5 lb (2.26 kg) of dead weight on the 30:1 ratio lever system. Test duration is 5000 cycles.

2.2 Three determinations are made:

¹ Under the standardization procedure of the Society, this method is under the jurisdiction of the ASTM Committee D-2 on Petroleum Products and Lubricants. A list of members may be found in the ASTM Year Book.

Accepted Sept. 13, 1968.

This method was prepared under the joint sponsorship of the American Society of Lubrication Engineers with the cooperation of the Coordinating Research Council, Inc. (CRC) Aviation Committee on Bonded Solid-Film Lubricants.

Accepted by ASLE Sept., 1968.

(1) The friction force after a certain number of revolutions, (2) the average width of the wear scar on the stationary block at the end of the test, and (3) the weight loss for the stationary block at the end of the test.

3. Significance

3.1 This method is used for the calibration of a ring and block testing machine by measuring the friction and wear properties of a calibration fluid under the prescribed test conditions. No correlation has been established between this test method and service. If the test conditions or the fluid are changed, wear values may change and relative rating of the fluid may be different.

4. Apparatus

4.1 *LFW-1 Friction and Wear Testing Machine*,² shown in Fig. 1 and described in detail in the Appendix.

4.2 *Test Ring*,³ of SAE 4620 steel having a Rockwell hardness of HRC 58 to 63. The rings have a ground face of 0.321 ± 0.005 in. (8.15 ± 0.127 mm)

² The Alpha LFW-1 machine is available from Dow Corning Corp., Testing Machines Dept., 65 Harvard Ave., Stamford, Conn. 06904.

³ Available from Dow Corning Corp., Testing Machines Dept., 65 Harvard Ave., Stamford, Conn. 06904.

wide and a diameter of $1.3775 \pm 0.0001 - 0.0005$ in. ($35 \pm 0.0025, -0.1270$ mm) having an eccentricity between the inner and outer surface no greater than 0.0015 in. (0.038 mm). The surface finish range of the outside diameter surface of the ring should be from 5 to 15 μ in. rms, in the direction of motion.

4.3 *Test Block*,³ of SAE 01⁴ cold work tool steel with test surface $0.250 \pm 0.0005, -0.0000$ in. ($0.635 \pm 0.012, -0.0000$ mm) wide and 0.620 ± 0.005

5. Reagents

5.1 *Benzene*, thiophene-free, conforming to ASTM Specification D 2359, for Refined Benzene-535.⁵

5.2 *Methyl Ethyl Ketone* (MEK), conforming to ASTM Specifications D 740, for Methyl Ethyl Ketone.⁵

5.3 *Petroleum Spirits*, conforming to ASTM Specifications D 235, for Petroleum Spirits (Mineral Spirits).⁵

5.4 *Calibration Fluid*, consisting of

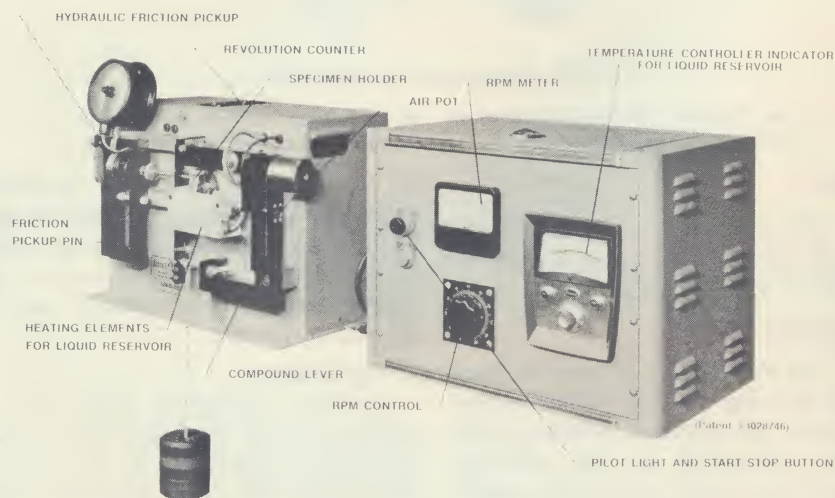


FIG. 1—Alpha LFW-1 Variable Drive Testing Machine.

in. (1.57 ± 0.127 mm) long having a Rockwell hardness of $HRC 30 \pm 3$. Each block is supplied with the test surface ground to a surface finish of 4 to 8 μ in. rms, being perfectly square with all outside edges.

4.4 *Analytical Balance*, capable of weighing to the nearest 0.1 mg.

4.5 *Measuring Magnifier Glass*, with metric or U.S. Customary unit calibration so that scar width can be measured with a precision of 0.05 mm, or equivalent.

SAE 01 is also known as Starrett 496 or Marshall Oilcrat.

6. Preparation of Apparatus

6.1 Before each test, thoroughly clean the specimen holder and the oil cup as well as the tapered section, threaded section, lock nut, and lock washer. Use benzene as the cleaning agent and rinse with methyl ethyl ketone.

6.2 Clean a new test ring and block for each test using the following pro-

³ 1968 Book of ASTM Standards, Part 20.

cedure: Immerse in petroleum spirits and scrub with a lint-free cloth. Rinse in a second bath of petroleum spirits. Suspend in the vapor of boiling benzene for 30 s, then immerse in boiling methyl ethyl ketone for 30 s. Allow part to drip-dry and again suspend with vapor of boiling benzene for 30 s. Allow to air-

points in the apparatus, such as the threaded portion of the test shaft and the brass bushing, with the oil to be tested. Care should be taken not to contaminate the oil being tested by the E.P. grease. Mount the test ring on the test shaft taking care not to touch the test area. Lock the test ring on the shaft

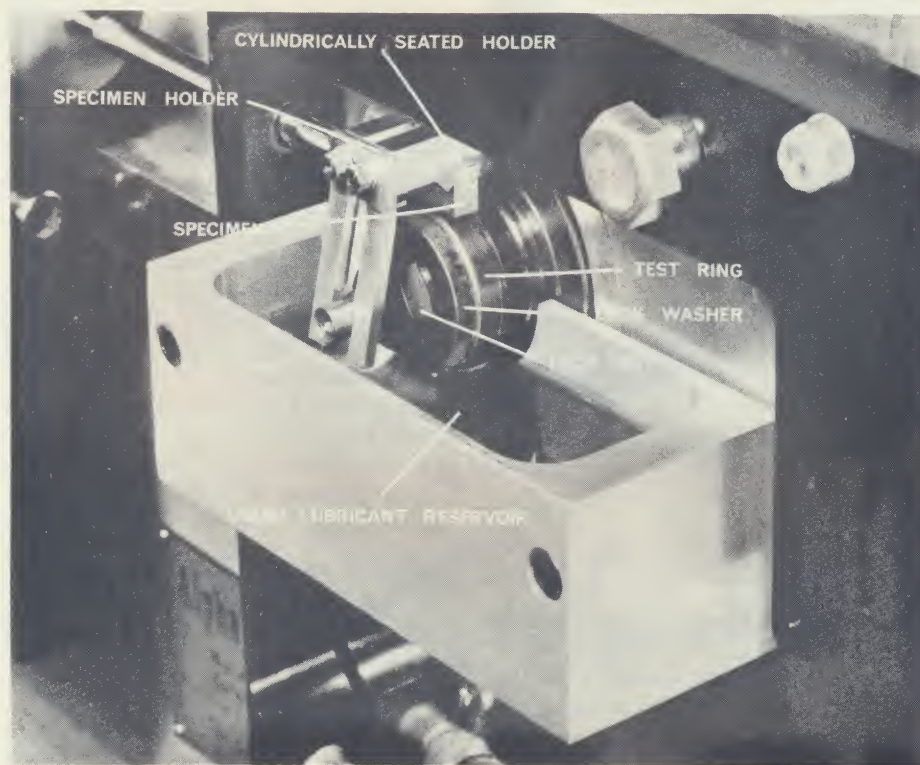


FIG. 2—Close-Up View of Specimen Holder and Liquid Reservoir.

dry, then weigh each test ring and test block to the nearest 0.1 mg on the analytical balance. Then store the specimens in a desiccator until ready for use.

6.3 Lubricate the quarter segment of the specimen holder with an E.P. grease, molybdenum disulfide fortified (approx 60 percent MoS_2).⁶ Lubricate other

⁶ Molykote G or equivalent has been found satisfactory.

with 250 in·lb (28.8 cm·kg) of torque using a torque wrench. Locate the oil cup in position and fill with test fluid to a level such that 0.25 in. (0.64 mm) of the test ring is immersed as shown in Fig. 2. This volume (approx 200 cm^3) should be measured and the same amount used for each test. Set the temperature control of the oil reservoir to 110 F. It is preferable to control the temperature of the liquid being tested,

but if the machine is not equipped with a temperature controller indicator, then record the liquid temperature. Turn on the machine and allow the test ring to rotate while the liquid is being heated. Continue rotation at 72 rpm for 5 min after the liquid reaches 110 F to permit the entire system to attain thermal equilibrium. Having stabilized at the required temperature, stop the machine and mount the test block. Make sure that the block is centered on the test ring and that the mating surfaces are perfectly aligned. This is accomplished by making certain that the specimen

machine at 5000 revolutions. Remove the test block and test ring and clean them thoroughly according to the following procedure: Scrub in a benzene bath with a lint-free cloth and rinse in methyl ethyl ketone; remove any excess wear particles that might have accumulated on the side of the scar by brushing with a soft camel's-hair brush; weigh the test ring and test block to the nearest 0.1 mg and measure the width of the wear scar of the test block at three points, in the center and one millimeter away from each edge, as shown in Fig. 3. Four tests are required to establish a satisfactory average.

8. Calibration

8.1 A machine shall be judged to be in acceptable condition if the results obtained on the calibration fluid fall within these limits:

8.1.1 Wear measurement between 1.70 and 2.90 mm.

8.1.2 Friction force after 4500 revolutions between 15.0 and 22.0 lb (6.81 and 9.97 kg).

9. Calculations and Report

9.1 Report the friction force at 200, 400, 600, and 4500 revolutions, the weight loss for the test block and test ring, and the average wear scar width.

9.2 Calculate the coefficient of friction values from the friction force value as follows:

$$f = \frac{F}{W}$$

where:

f = coefficient of friction,
 F = measured friction force, lb, and
 W = normal load, lb.

10. Precision

10.1 The following criteria should be used for judging the acceptability of test results (95 percent probability).

10.1.1 Wear Measurement:

10.1.1.1 *Repeatability*—Duplicate results by the same operator should be considered suspect if they differ by more than 0.73 mm.

10.1.1.2 *Reproducibility*—The results submitted by each of two laboratories should be considered suspect if they differ by more than 1.20 mm.

10.1.2 Friction Force After 4500 Revolutions:

10.1.2.1 *Repeatability*—Duplicate results by the same operator should be considered suspect if they differ by more than 6.6 lb (3.0 kg).

10.1.2.2 *Reproducibility*—The results submitted by each of two laboratories should be considered suspect if they differ by more than 7.0 lb (3.16 kg).

APPENDIX

A1. DESCRIPTION OF THE LFW-1 FRICTION AND WEAR TESTING MACHINE

A1.1 A stationary rectangular test block is pressed with a predetermined load, maximum 630 lb (283 kg), against a rotating ring (Fig. A1). The load is accurately maintained throughout the test. Bearing pressures (average Hertz pres-

machine will automatically shut off upon reaching it.

A1.3 In a substitute method, a thermocouple is embedded in the specimen and a temperature recorder controller (not standard equipment)

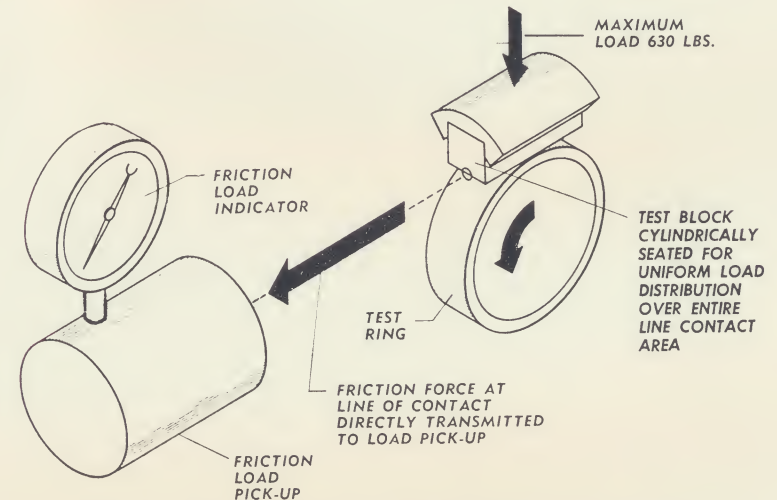


FIG. A1—Functional Diagram of Alpha LFW-1 Testing Machine.

ures) in the line contact area between the rectangular specimen and the rotating ring may range up to 110,000 psi (7700 kgf/cm²).

A1.2 Resulting friction is indicated throughout the test by a dial indicator. A counter records the number of revolutions of the test specimen. One criterion in the test is when friction reaches a preselected maximum. For this purpose a control pointer on the friction indicator can be set for any preselected value of friction and the

terminates the test when the temperature of the test block reaches a previously set value.

A1.4 The test shaft of the machine is supported by two roller bearings and the mandrel end of the shaft protrudes through the front panel of the machine where the test specimens are mounted. The test block, which is held stationary against the revolving ring, is restrained from horizontal movement by a unique type of holder. The design of this block holder

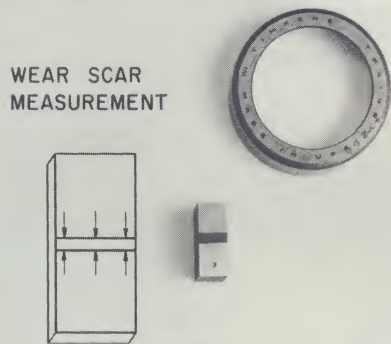


FIG. 3—Test Specimen Wear Scar Measurement.

holder is free during mounting so that the quarter segment can properly seat itself.

7. Procedure

7.1 With the revolution counter set at zero, gently place a 5-lb (2.26-kg) load on the bale rod, being very careful to avoid shock-loading. Start the machine and bring the speed to 72 rpm making sure at this point that the reference markers are perfectly aligned. Record the friction force and the temperature of the liquid at 200, 400, 600, and 4500 revolutions and check the speed and the reference marker alignment at each of these times. Stop the

allows the test block to align itself automatically in a manner prescribed by ASTM specifications for compression-loaded specimens. This maintains uniform loading throughout the area of contact between the specimens regardless of the force existing between them.

A1.5 The normal force between the test specimens is produced by hanging dead weights on the lower end of a compound lever system which is designed in such a way as to allow the full value of the friction force to be transmitted to the frictional load pickup device.

A1.6 The friction force indicator is direct reading in pounds or kilograms and is fitted with an infinitely adjustable limit control which allows the operator to preset the value of friction at

which the machine will stop. This setting is accomplished without the use of tools by a knurled knob located in the center of the dial face outside of the glass.

A1.7 A six-digit revolution counter is panel-mounted in the top of the case. It is driven from the test shaft and is equipped with a reset wheel which can be controlled from the outside of the case.

A1.8 The machine is furnished complete with all electrical equipment ready to operate after removal of a few shipping bolts. Besides the motor, the electrical equipment includes control circuit relays and push-button-controlled magnetic motor starter for electrical overload and low-voltage protection.

Testing Dry Film Lubricants for Space Use

Failure of aluminum-bronze bushings in space applications was traced to corrosion effects during storage by combination of salt spray and wear tests

by Frans G. A. DeLaat

Not too long ago in the aerospace industry, an unusual problem developed with aluminum-bronze bushings in critical mechanisms—corrosion and excessive wear resulted from improper use of several types of solid dry film lubricants. The need for an immediate solution to the problem led to a double-barreled program to:

1. Determine the corrosive effects of solid dry film lubricants applied to aluminum-bronze.
2. Quickly obtain highly accurate data on the friction and wear life of aluminum-bronze bushings after exposure to a corrosive environment.

Aluminum-bronze always has been widely accepted as a bushing material for satellite and manned spacecraft programs. It has good strength characteristics, is easily machinable, has inherent lubricity against hardened steel and is compatible with outer space conditions. Such bushings are used frequently in journals, pins and clevises, where loads are transmitted through a pivoting motion in various linkages and shafts.

To increase lubricity in hard vacuum, however, the bushings were treated with several solid dry film lubricants consisting of both inorganic and organic binders and with lubricity constituents of molybdenum disulfide, graphite, lead sulphide and tin. The treated aluminum-bronze bushings were installed in space-

craft systems that invariably were stored for up to one year prior to vehicle launching.

Corrosion Is Problem

Since most aerospace launching pads and storage facilities are located close to the oceans, the bushings were subjected to a corrosion-inducing environment. Corrosion developed and accelerated, causing the formation of green-blue copper oxides on the bushing surfaces.

The corrosion build-up in most cases was actually about 5-10 times thicker than the lubricant coatings. These corrosive products formed a highly abrasive film on top of and under the solid dry film lubricants. Coating adhesion was disrupted and the lubricants were lifted off in flakes. The initial fungal-like growth usually occurred on the ends of the bushings, on the outside of the mechanism. While corrosion did not originate on the enclosed parts of the bushings, it did ultimately propagate inwards to the farthest recesses of the aluminum-bronze.

The results of corrosion were quite serious. Lubricity disappeared almost completely, and the high friction and torque caused shafts to jam and make critical components inoperable. The corrosion by-products

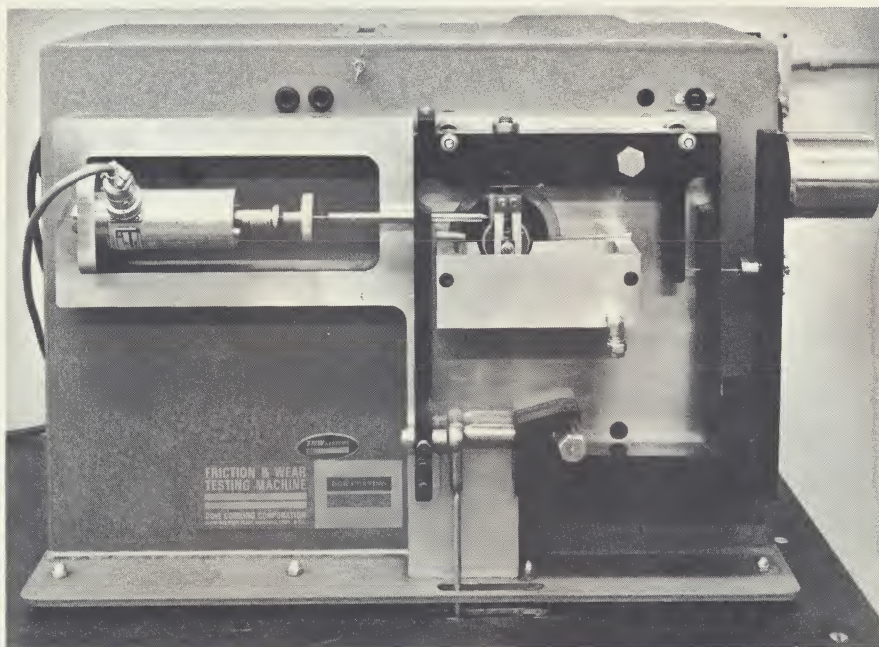


Fig. 1. Aluminum-bronze rotating test ring and stationary steel test block are mounted at center of LFW-1 friction and wear testing machine faceplate. Test pieces are held by specimen holder connected by friction force rod to load cell at left. At bottom of machine is rod to which full load of 630 pounds (not shown) is attached.

also severely pitted, scored and galled the steel, titanium and anodized aluminum wearing surfaces, the worst effects being on the steel. Bearing seizure was the inevitable outcome in all of the bushings in addition to the malfunction of overworked power sources.

Solution for Corrosion Problem

Three solid dry film lubricants utilized in the aerospace industry were tested:

1. Inorganic—a sodium silicate binder with molybdenum disulphide and graphite (MIL-L-81329). This is the first solid dry film lubricant, used widely in the aircraft industry for over 14 years.

2. Inorganic—a proprietary binder system with molybdenum disulphide, graphite and lead sulphide. This is a complex binder established on a surface by electrophoresis.

3. Organic—a dual phenolic resin binder with molybdenum disulphide, graphite and tin. It is one of the very few organic materials that has favorable outgassing properties in vacuum.

The three lubricants were applied to panels of aluminum-bronze (Fed. Spec. QQ-C-465, Alloy No. 642) and tested in salt spray under federal Test Method 151. This particular test requires a 20 per

cent salt spray environment for 50 hours at ambient temperatures in an enclosed chamber.

Following the salt spray test period, the electrophoretic and organic solid dry film lubricants showed satisfactory corrosion resistance, in that both still retained some lubricity. These two types of lubricants apparently seal off the surfaces of the aluminum-bronze to some extent and in this way inhibit salt spray corrosion.

The sodium silicate, on the other hand, exhibited virtually disastrous effects. The lubricant was either entirely discolored, removed from the aluminum-bronze, or completely dominated by the rough surface growth. These findings were confirmed conclusively when it was learned that the spacecraft mechanisms with the worst corrosion failures were those in which the aluminum-bronze bushings had been lubricated with the inorganic material utilizing the sodium silicate binder.

Friction/Wear Testing Program

The second important phase of the test program was to ascertain the friction and wear life of the three solid dry film lubricants on aluminum-bronze, under conditions involving unidirectional motion. To obtain

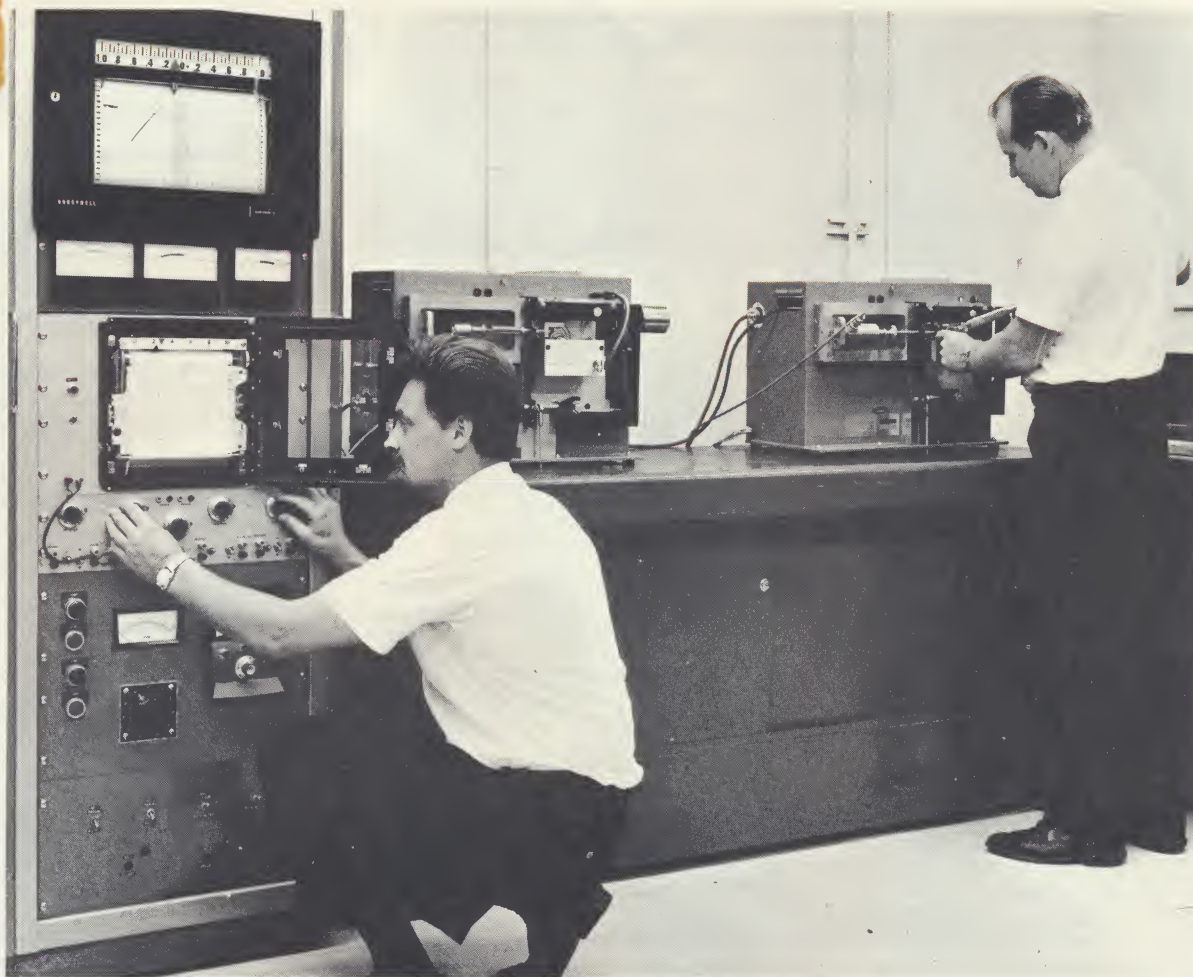


Fig. 2. TRW Systems friction and wear test equipment includes two LFW-1 units, control consoles for varying test parameters and recorders for recording frictional forces and temperatures.

unquestionable accuracy in a very short time and at relatively low cost, an LFW-1 friction and wear testing machine (Figs. 1 and 2) was employed exclusively. Manufactured by the Dow Corning Corporation at Stamford, Connecticut, this machine can be considered unique in the field of lubricant testing because it eliminates the need to construct special test equipment and to test actual expensive components. In the case of the aluminum-bronze bushings, the alternative to the testing machine would have been to design and build a special journal bushing bearing tester, at a cost 20 to 100 per cent greater. This approach also would have necessitated making full size aluminum-bronze bushings and steel journals, and applying strain-gauges and other instruments to the components for accurate measurement of friction coefficients and wear life.

With the LFW-1, the test specimens can be quite small and the number held to a minimum. This reduces the cost of fabrication of test parts to about one-tenth that of making the bushings and journals. In addition, the small test pieces permit more economic

repetition of tests in the salt spray chamber and on the testing machine, and eliminate the necessity of testing and subsequently ruining expensive journals and bushings.

For the friction and wear tests, a Timken ring (Fig. 3) was made from aluminum-bronze. The small stationary test block was made from 4130 low alloy chrome steel and represented the journal, pin or shaft. The surface finish on the ring was 15 microinches rms, and on the block 6 to 12 microinches rms. Since the line contact between the rotating ring and stationary block simulated exactly the line contact in the journal bushing bearing, the correlation between the test and spacecraft application was the closest that could be obtained.

It should be noted that only the test ring was treated with the solid dry film lubricant. With the stationary steel block bare, the simulation was the actual condition occurring in a journal bushing, where the journal represents the fixed pin or shaft and the ring the rotating, lubricated aluminum-bronze bushing. All of the tests were performed at 72 rpm at a load of 630

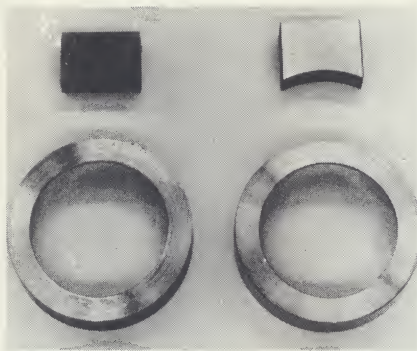


Fig. 3. Typical corrosion test specimens are aluminum-bronze rotating rings and stationary blocks made of 4130 low alloy chrome steel. Rings simulate bushings; journal blocks represent fixed pins or shafts. Conforming steel block (right) is used for full surface contact at lower load levels.

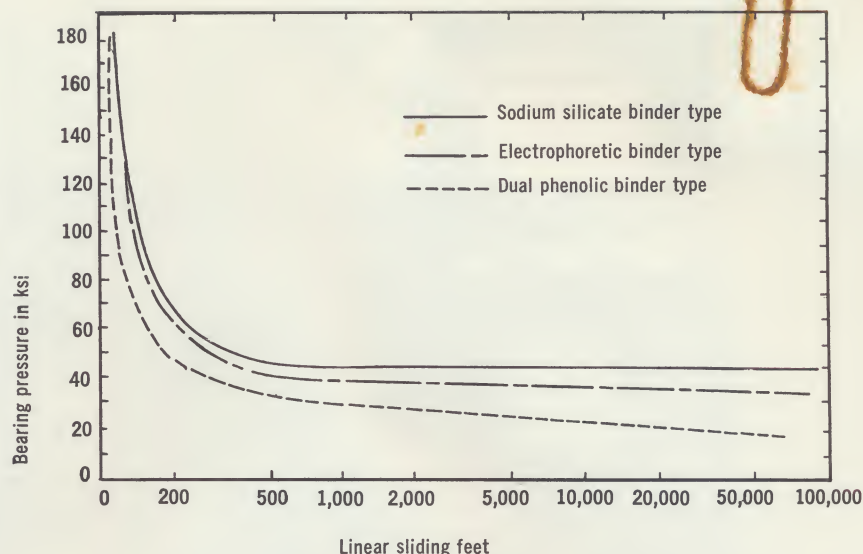


Fig. 4. (above right) Wear test results show relation of life to bearing pressure.

pounds. The significance of bearing pressure is shown in Fig. 4.

In the bench-type testing machine, the friction force rod is connected to a load cell, which is a device to measure extremely fine differences in frictional forces. Loading is accomplished through four pivot flex members that keep the loads continuously normal to the surface of the rotating ring and prevent the specimen from jumping under load.

Testing revealed that the kinetic friction coefficient of the three solid dry film lubricants did not exceed 0.05, which is extremely low. However, the wear life of the sodium silicate lubricant was about 8.5 per cent higher than the electrophoretic, and the electrophoretic wear life was about 35 per cent higher than the organic. There was no question that the sodium silicate was the best lubricant on aluminum-bronze, but it was also the most prone to corrosion in a marine environment. Detailed results are given in the table.

Tests Result in Other Useful Dry Film Lubricants

Several significant conclusions were drawn from the salt spray and friction/wear testing of aluminum-bronze.

1. Sodium silicate solid dry film lubricants cannot be used on aluminum-bronze bushings subjected to long-term exposure to marine environments and high humidity. The lubricant is apparently hygroscopic and attracts and traps moisture to generate a galvanic current between the lubricant coating and substrate material. Further laboratory and field testing also revealed that sodium silicate should be applied only to surfaces that have been previously protected against corrosion, such as chrome-, nickel- or cadmium-plated steel surfaces, and anodized aluminum, magnesium or titanium surfaces.

2. When sodium silicate was replaced by electrophoretic and organic binder types of solid dry film

Friction, Wear and Corrosion Data					
Lubricant system	Friction and wear test data*			Corrosion rating observations	
	Kinetic coefficient friction range	Wear life expressed in linear sliding feet	PV factor†	After 25 hr	After 50 hr
Sodium silicate	0.009—0.026	95,900	1,092,000	Poor	Poor
Electrophoretic	0.017—0.043	89,300	988,000	Good	Fair to Good
Dual phenolic	0.016—0.037	65,700	728,000	Good	Good

*Based on an average of three tests.

†Pressure (psi) times the velocity (ft/min). Pressure values as stabilized at that part of the test where the curves of Fig. 4 straighten out.

lubricants, the jamming and freezing of spacecraft hardware due to bushing corrosion ceased. The electrophoretic system is regarded as the optimum lubricant on aluminum bronze bushings for aerospace equipment. Nevertheless, both the electrophoretic and organic lubricants are now used in major aerospace and manned space projects, and specifications have been written so that quality control can be maintained for years to come.

3. For the first time it was realized that other types of solid dry film lubricants, both inorganic and organic, could be used successfully in a vacuum environment to lubricate critical components without failure, yet eliminate problems of corrosion on aluminum-bronze bushings. □